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Session 9: Particulate Matter Characterization

SIZE-SELECTIVE MEASUREMENTS OF ULTRAFINE PARTICLE EMISSIONS FROM A CNG AND A TRAP-EQUIPPED DIESEL BUS DURING TRANSIENT OPERATION

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ABSTRACT

Two Scanning Mobility Particle Sizers (SMPS) was used in size-selective mode (i.e., panel mode) to measure the transient emissions of ultrafine (UF) particles from two transit buses. The vehicles were both 40-passenger New Flyer chassis powered by DDC Series 50, 8.5 L engines. One was a model year 2000 CNG-fueled bus without aftertreatment. The second was a model year 1998 diesel bus retrofit with a diesel particle filter or an oxidation catalyst. The diesel fuel was ECD-1 ultra-low sulfur diesel provided by BP. Two sampling locations were used: (1) raw exhaust sampling using a Dekati partial-flow mini-diluter and (2) sampling of diluted exhaust from the CVS tunnel. The vehicles were operated on a chassis dynamometer at CARB's Heavy-duty Emissions Laboratory over three transient cycles (CBD, UDDS, and NYBC). When operated in panel mode, the SMPS does not scan, and therefore acts as a mobility classifier by selecting and counting particles in narrow diameter ranges in real time. The transient particle size distribution could be represented as the aggregate of multiple "panel-mode scans." The mobility diameters of interest were 8, 20, 80, and 140 nm. Sampling line lengths were minimized and flow rates were as nearly identical as possible for both sampling locations. Results were not corrected for losses in sampling lines.

The subject of this paper complements the presentation by our group at the last CRC Workshop. Then, we discussed size distribution results from SMPS full scans (i.e., analog mode) under steady-state operation. Now, we complete the treatment of UF particle emissions by offering transient sizing results. The central focus of our study is the suitability of this instrument for transient UF particle measurements and the impact of dilution approach. The size-selective raw data from the SMPS was converted to number concentrations after corrections for the transfer function, charging probability, and flow rates. In total, more than 50 panel mode samples were collected over the three driving cycles and for three bus configurations. As expected, differences in concentrations as a function of bus type, particle size, and duty cycle were observed.

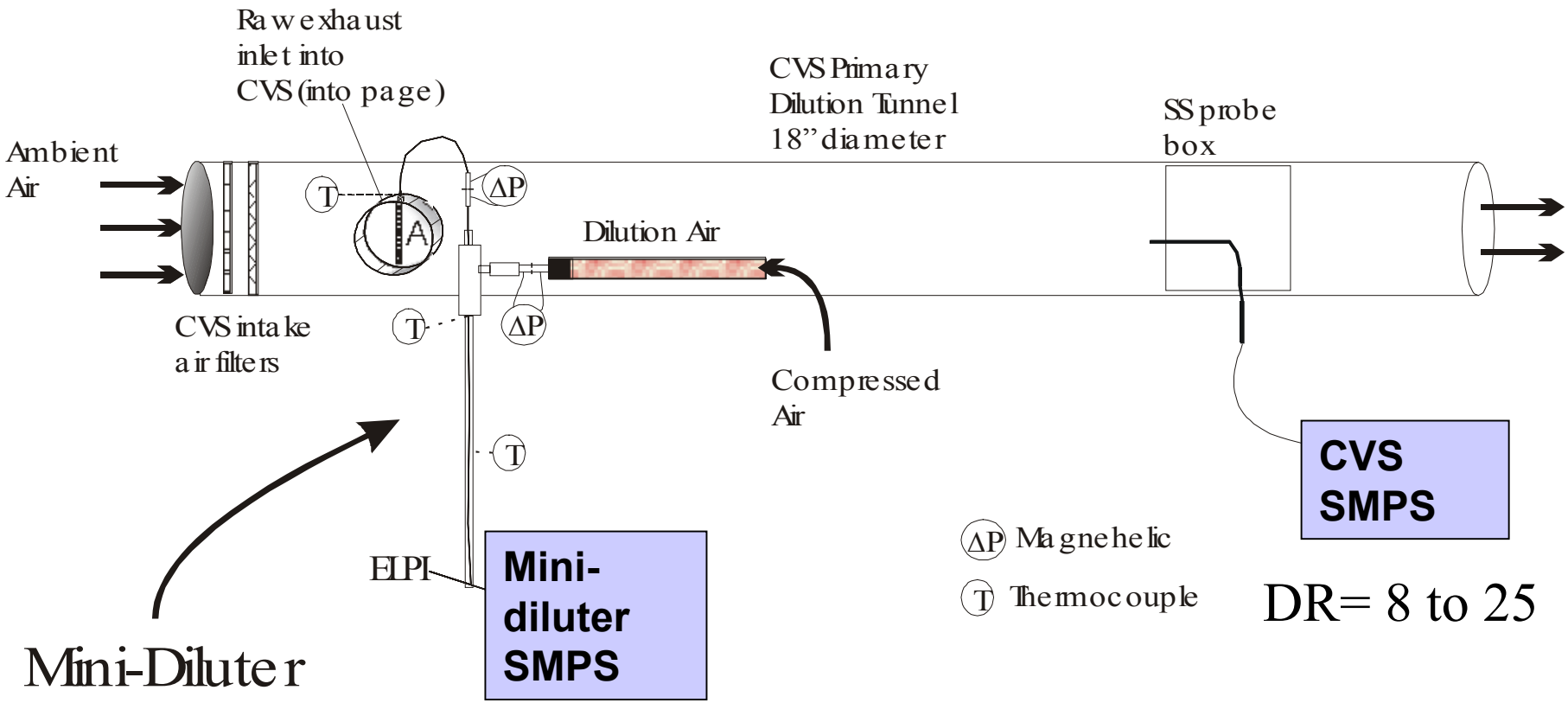
In general, peaks in the real-time single-size number concentrations observed at both sampling locations corresponded to peaks in vehicle speed. More sample-to-sample variation in terms of duty cycle and sampling location was noted in the CNG bus results than for the trap-equipped vehicle. In the CNG emissions, we detected a tendency toward higher number concentrations for the smaller particles. Tests for the trap-equipped bus returned number concentrations that varied less than CNG concentrations as a function of size or cycle.

Overview

CARB Bus Emissions Study

- Some results presented at previous CRC Workshops
- Collaborative effort: CARB, UCD, UCONN, SCAQMD
- Chassis dynamometer testing of in-use buses:
  - 1998 DDC S50 diesel engine (ULSD)
  - 2000 DDC S50 CNG engine
- 40-foot transit buses
  - Baseline Diesel (w/ DOC),
  - Diesel+CRT, and
  - CNG (no after-treatment)

Two Sampling Stations



Scanning Mobility Particle Sizer
Operated in Single-Diameter Mode

- TSI 3080 Classifier, 3025A CPC
- 1.45 Lpm aerosol flow rate (14.5 Lpm sheath)
- dN/dlogDp (AIM ver4.3)
- No DR correction in results presented here
- 8, 20, 80, and 140nm

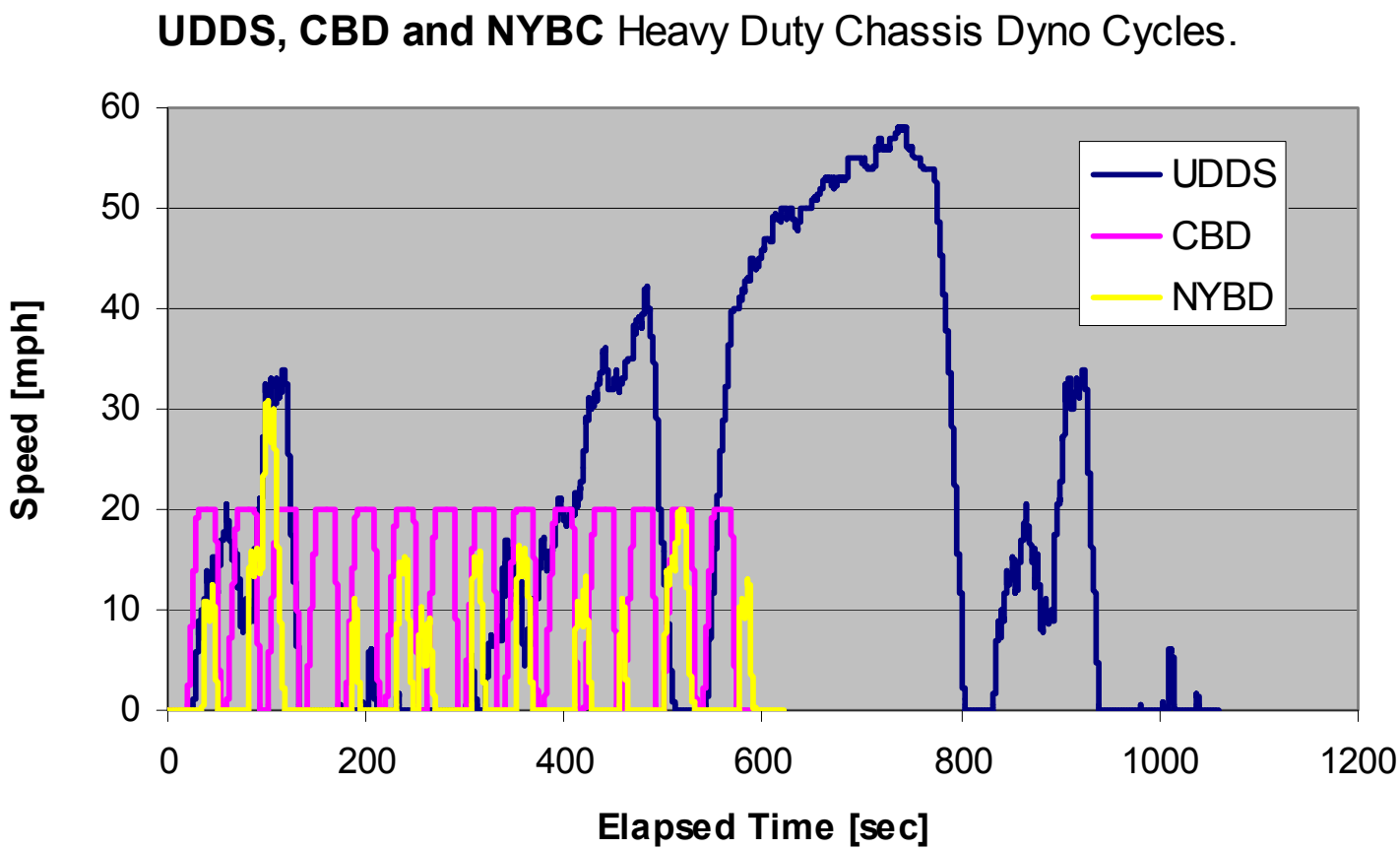
SMPS Particle Size Distributions Focus

- Single-diameter transient cycle (CBD, NYBC, UDDS)
- Results presented for particle size of 8, 20, 80, and 140nm

Collected Samples from Transit Buses

Particle Size / Bus Type	8nm	20nm	80nm	140nm
Baseline Diesel	CBD	CBD		
Trap-equipped Diesel	CBD NYB UDDS	CBD NYB	CBD NYB UDDS	CBD NYB UDDS
CNG^{+} or CNG-Retest*	CBD^{+*}	CBD^{+*} NYB* UDDS*	CBD^{+*} NYB* UDDS*	CBD^{+*} NYB* UDDS*

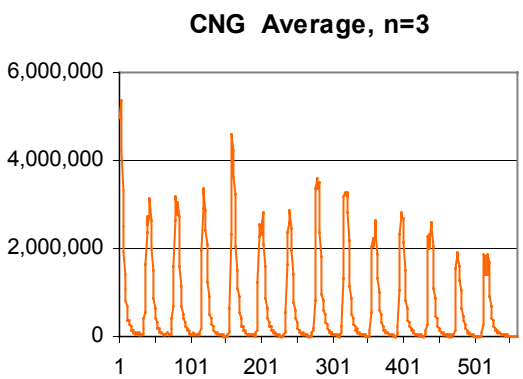
Transient Driving Cycles

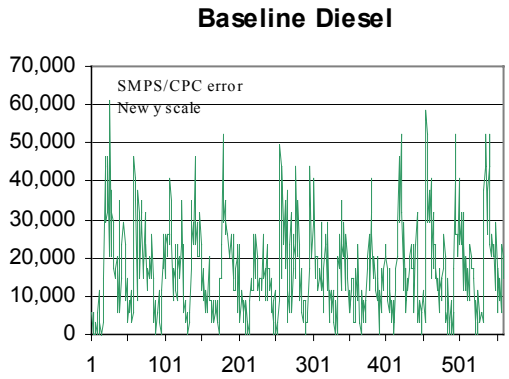


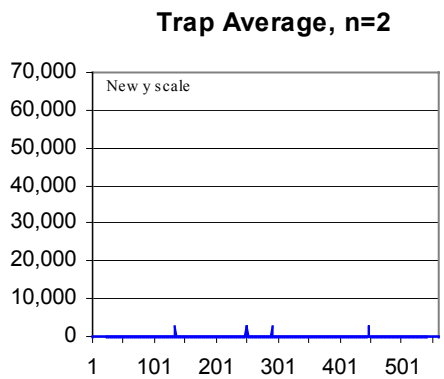
RESULTS FOR THE SMALLEST PARTICLES (8 nm)

Comparison of Technologies - CBD Cycle 8nm

CVS

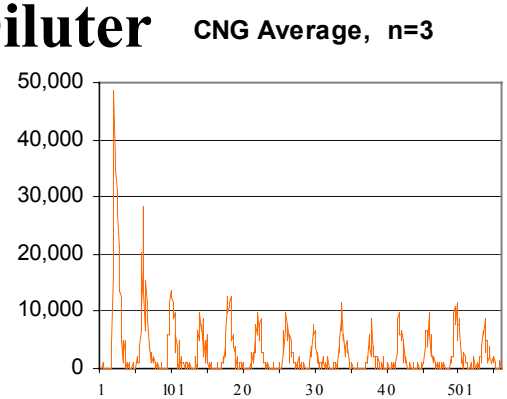


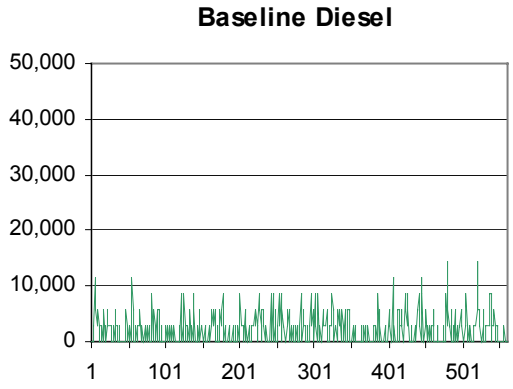


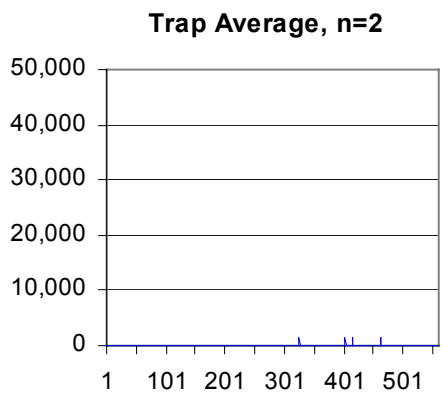


- 8nm particle emissions lower for Diesel than for CNG, Trap is very efficient
- CNG and Diesel emissions correlate with engine operation (i.e., cycle)

Mini Diluter





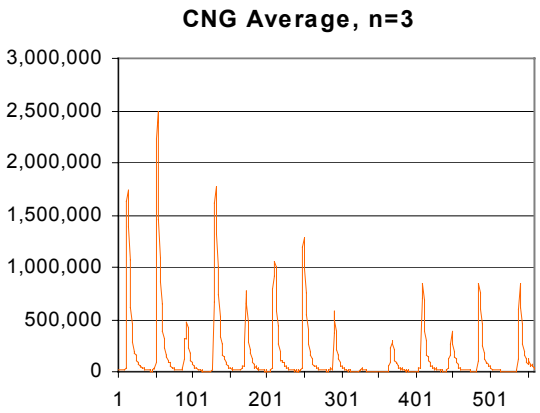


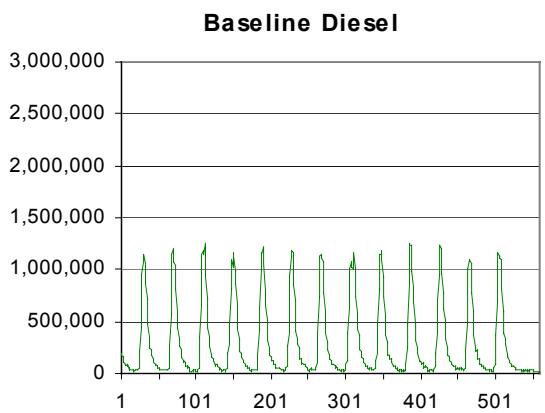
- Mini Diluter and CVS have different DLR, but give the same results

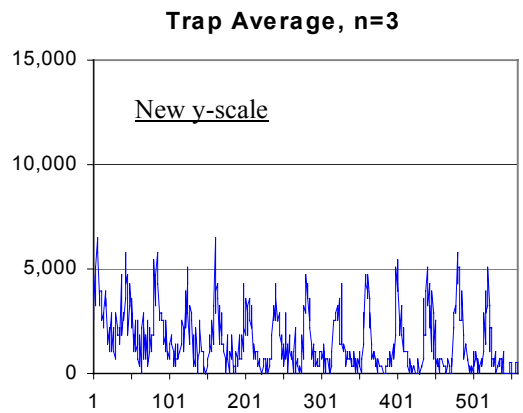
RESULTS FOR THE 20 nm PARTICLES

Comparison of Technologies - CBD Cycle 20nm

CVS

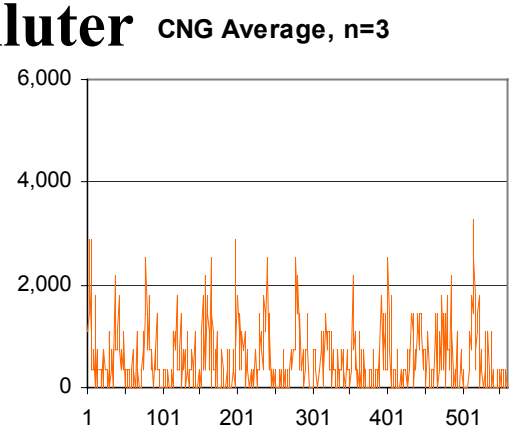


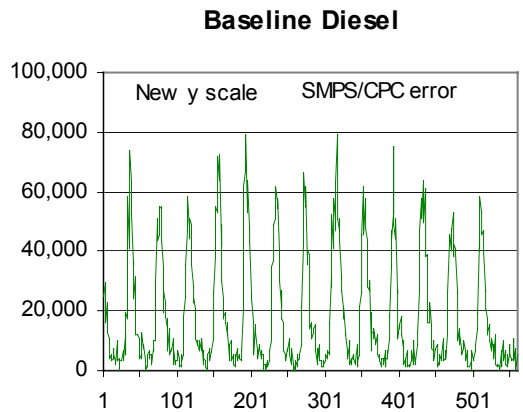


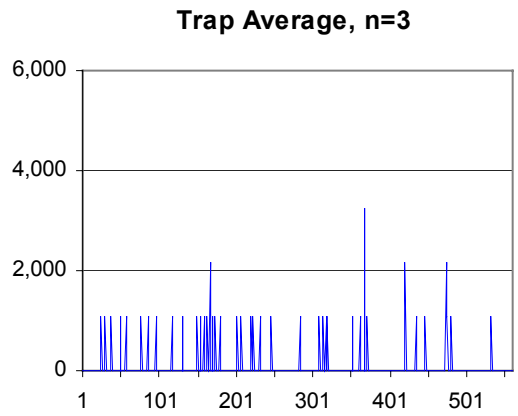


- 20nm particle emissions comparable for Diesel and CNG, Trap is very efficient
- Emissions from all three technologies track duty cycle

Mini Diluter





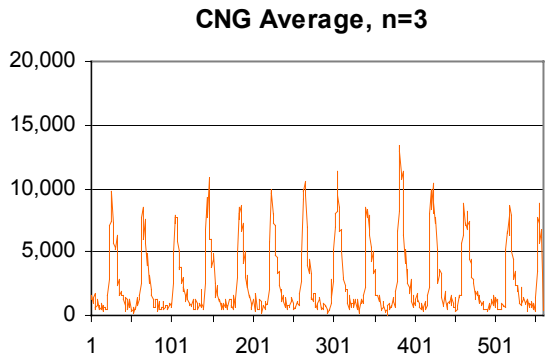


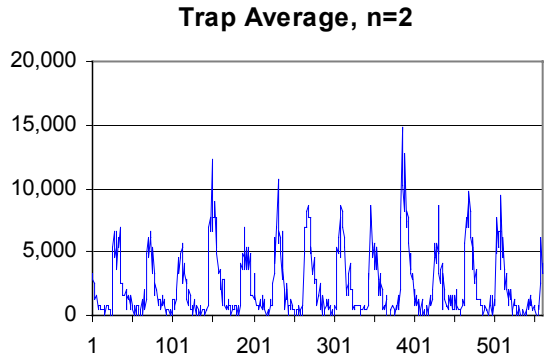
- Relative CNG to Trap concentrations appear to have changed from CVS
- Mini Diluter has lower resolution than CVS

RESULTS FOR 80 nm PARTICLES

Comparison of Technologies - CBD Cycle 80nm

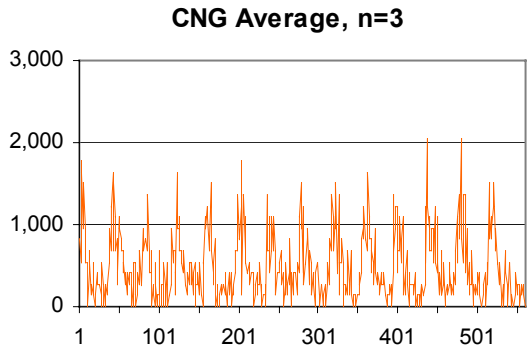
CVS

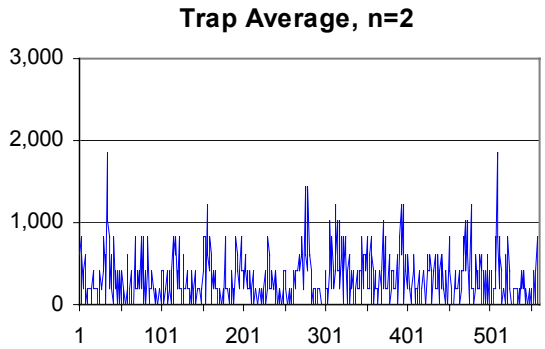




- 80nm particle emissions comparable for CNG and Trap
- Emissions from both technologies dependent on engine operation

Mini Diluter



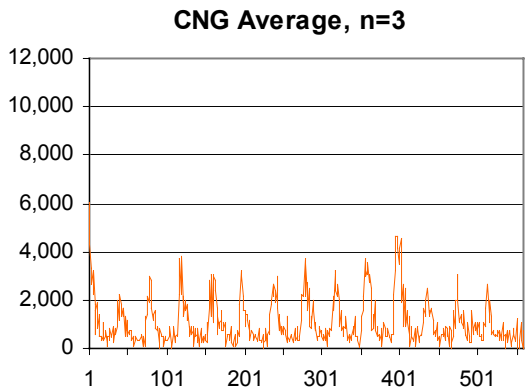


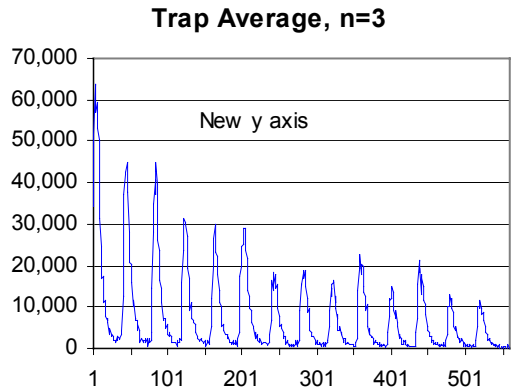
- CVS and Mini Diluter give same relative result
- Mini Diluter has lower resolution than CVS

RESULTS FOR 140 nm PARTICLES

Comparison of Technologies - CBD Cycle 140nm

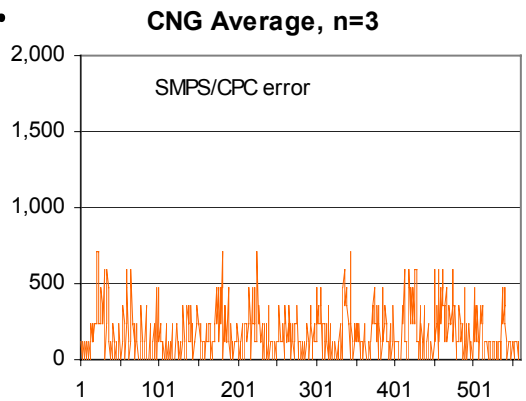
CVS

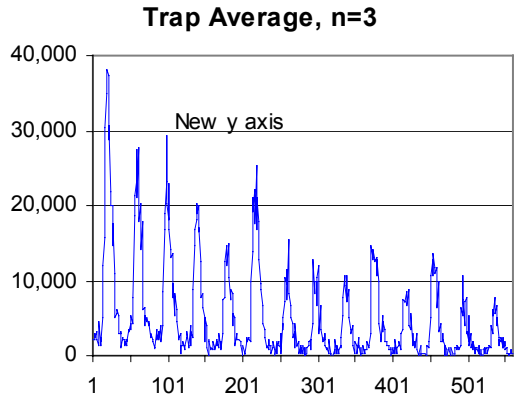




- 140nm particle emissions comparable for CNG and Trap for two out of three samples. Third Trap sample has 40x greater concentrations than first two
- Emissions from both technologies dependent on engine operation

Mini Diluter

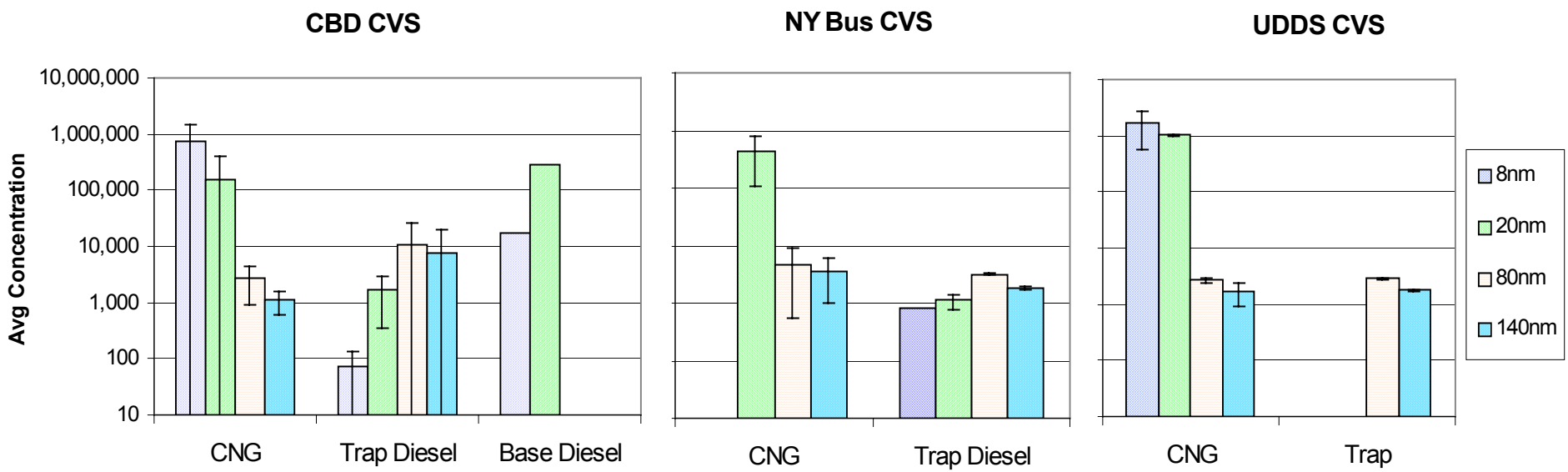




- CVS and Mini Diluter give same relative result
- Mini Diluter has lower resolution than CVS

Comparison of Cycles

Cycle Mean Concentrations



- Particle number distribution peaks in the smallest size for CNG and at 80nm for Trap diesel
- Average concentrations vary by an order of magnitude or less between cycles

* Error bars represent 1 standard deviation of repeated samples.

Final Remarks

- SMPS single-size measurements are time consuming, but capable of capturing transient UF particle emissions.
- Differences at sampling locations (CVS vs Mini diluter) noted.
- Transient nanoparticle (8 nm) emissions highest for CNG.
- Diesel Trap and CNG result in similar UF particle number concentrations (80 and 140nm).
- Based on DR corrected data from Mini-Diluter, Diesel Trap reduces 8nm particles by 35-170 X compared to CNG and by >200 X compared to Diesel Baseline.
- Mean particle emission concentrations not greatly affected by driving cycle.
- In general, particle emissions track engine operation (i.e., duty cycle).
- Data collected at CVS sampling location has higher resolution than data collected at Mini Diluter location.

Acknowledgements

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